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Thin Film Femtosecond Laser Damage Competition

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Thin Film Femtosecond Laser Damage Competition

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ABSTRACT

In order to determine the current status of thin film laser resistance within the private, academic, and government sectors, a damage competition was started at the 2008 Boulder Damage Symposium. This damage competition allows a direct comparison of the current state of the art of high laser resistance coatings since they are tested using the same damage test setup and the same protocol. In 2009 a high reflector coating was selected at a wavelength of 786 nm at normal incidence at a pulse length of 180 femtoseconds. A double blind test assured sample and submitter anonymity so only a summary of the results are presented here. In addition to the laser resistance results, details of deposition processes, coating materials and layer count, and spectral results will also be shared.

Keywords: damage testing, mirror, thin film, multilayer, femtosecond laser

1. INTRODUCTION

Last year's damage competition tested a normal incidence high reflector with a 1064-nm wavelength laser and 5-ns pulse length.[1] Results of this test showed a range of damage thresholds exceeding two orders of magnitude. General trends in the data were e-beam deposited coatings clearly had the highest laser resistance, hafnia was the optimum high index material, silica overcoats had a positive impact on the laser resistance, and a plasma pre-cleaning of the surface also had a very positive impact on the laser resistance of the coating. This year femtosecond laser damage was the topic of the mini-symposium so a short pulse high reflector was selected for the damage competition due to increased interest in this emerging area and to complement the mini-symposium theme.

2. PARTICIPATION

Twenty-five samples were submitted to this competition from fifteen different companies or institutes listed in table 1. Up to two samples could be submitted by each participant. The participants came from four different countries; USA (11), Germany (9), Japan (3), and China (2) representing North America, Europe, and Asia respectively.

Table 1 List of participating companies or institutes for the BDS thin film damage competition.

Advanced Thin Films	Fraunhofer Institute for Surface Engineering and Thin Films	Gooch and Housego
Institute of Optics and Electronics, Chinese Academy of Sciences	Jenoptik Laser, Optik, GmbH	Laser Components
Laser Zentrum Hannover e.V.	Layertec Optical Coatings	Nikon Corporation
Okamoto Optics Work, Inc.	Precision Photonics Corporation	Quality Thin Films
Schott	Shanghai Institute of Optics and Fine Mechanics	Spectra-Physics

3. SAMPLES

The spectral requirements were a reflectance greater than 99.5% at 786 nm at normal incidence. Environmental requirements were ambient lab conditions (40% relative humidity and 20 degrees Celsius). There were no stress or reflected wavefront requirements. Substrates were supplied by the participant with dimensions of 50 mm in diameter and 10 mm thick. The substrate material was typically BK7. Participants were asked to provide a spectral plot to validate spectral performance, a description of the coating process, and the layer count. A list of the coating materials was also requested, but was not mandatory so nearly 25% of the participants declined to provide this information. Based on input from conference attendees, it is likely that the coating material will also become mandatory information on subsequent damage competitions.

Samples were removed from participant supplied packaging containers into identical PETG packaging containers in an attempt to remove any identification link to the supplier. Also, for anonymity, a unique code was assigned to each sample. The identity of the suppliers and sample was kept by an administrative assistant to maintain a double blind experiment. The author and damage testing service did not have access to the identity of any of the samples so as to remain unbiased and to protect the identities of participants whose samples were the least laser resistant.

At least six different coating deposition techniques were used to manufacture the submitted samples as shown in figure 1. The samples were deposited by electron beam deposition, ion beam sputtering, and magnetron sputtering. Some of the e-beam coatings were densified by either ion assistance or plasma assistance.

At least five different coating materials were used to manufacture the samples. Silica was the low index material of choice. The high index materials included hafnia, niobia, tantala, titania, and zirconia as illustrated in figure 2. One of the hafnia coatings had alumina as a third material. Participants declined to report the high index material for eight of the samples. The number of layers ranged from twenty to forty-six layers as illustrated in figure 3.

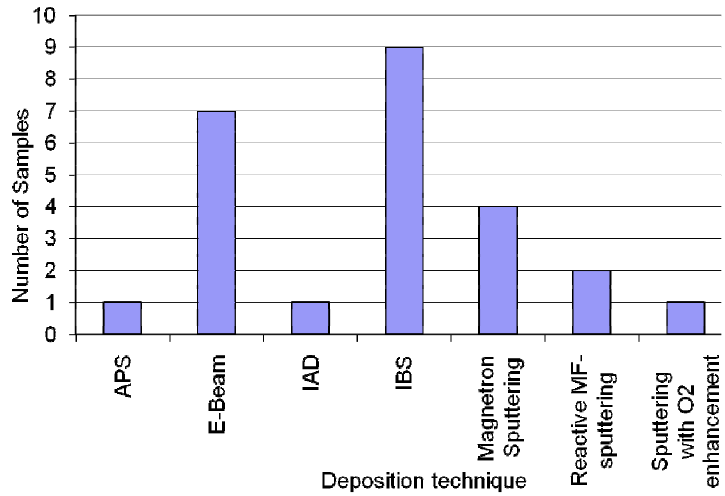

Fig. 1 Distribution of deposition technologies for the contributed samples.

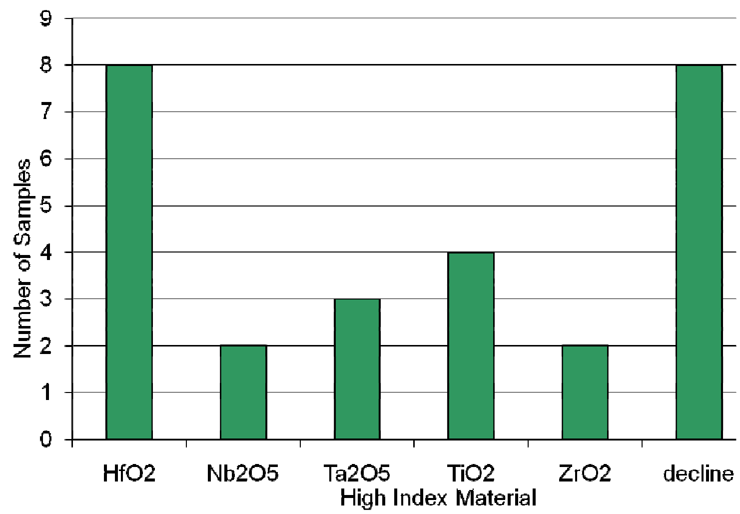

Fig. 2 Distribution of high index materials for the contributed samples.

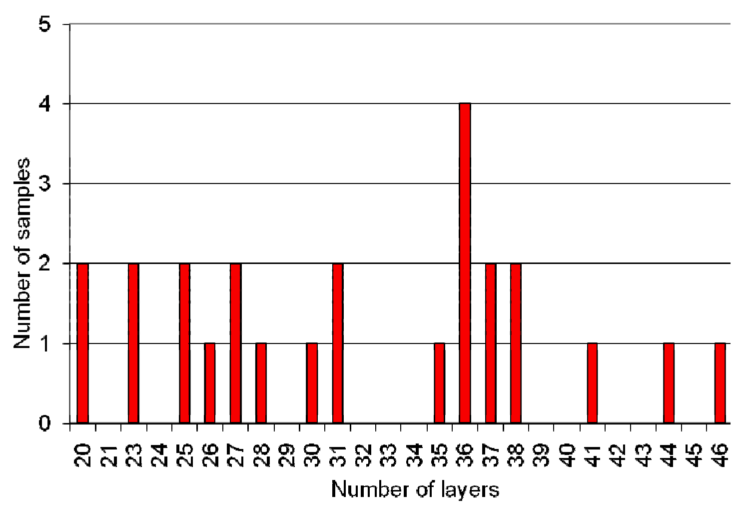

Fig. 3 Distribution of the number of coating layers for the contributed samples.

4. DAMAGE TESTING

The samples were tested at Laser Zentrum Hannover according to the S on 1-measurement procedure (Fig.4) stated in the International Standard ISO 11254-2 [2]. Within this experiment, a commercial CPA1000 laser (Clark-MXR) with a pulse duration of approximately 200 fs at a center-wavelength of 786 nm, a repetition rate of 1 kHz and a maximum output power of approximately 600mW was used. The effective beam diameter of the focused beam in the sample plane was measured by a beam profiling system and verified with the knife edge method according to ISO 11146 [3]. A beam diameter of 128µm was observed for the focusing lens with a focal length of 600 mm. The energy density on the sample surface can be varied continuously by a combination of a rotatable half-wave plate with a polarizer (TFP), which is designed for applications in the ultrashort pulse regime. To observe the status of the irradiated test site, the scattered light from the sample surface is monitored by a photodiode. A mechanical shutter with an opening time below 1ms is integrated in the measurement set-up to block the laser beam if damage is identified by the online detection system. To evaluate the irradiated energy density on the surface, the pulse energy of each pulse is measured by an additional calibrated photodiode. After the test, all samples were optically inspected by interference contrast microscopy (Nomarski-microscope), and the damage was correlated off-line with the in-situ damage detection system. The measurement procedure is performed in the 60,000 on 1 mode irradiating 160 test sites of each specimen with the laser beam. For each test site a binary dataset is generated, which contains the applied energy density, the charged number of pulses and the status of the test area. Using a data reduction technique comparable to the procedures described in ISO 11254-2, the final result of the S on 1-measurement, the characteristic damage curve is derived. Illustrating the development of the laser-induced damage threshold with an increasing number of pulses, the characteristic damage curve gives information about the laser resistance of the sample as a function of the pulse number. The 0% damage threshold for 60,000 pulses was chosen as the reference value for sample comparison.

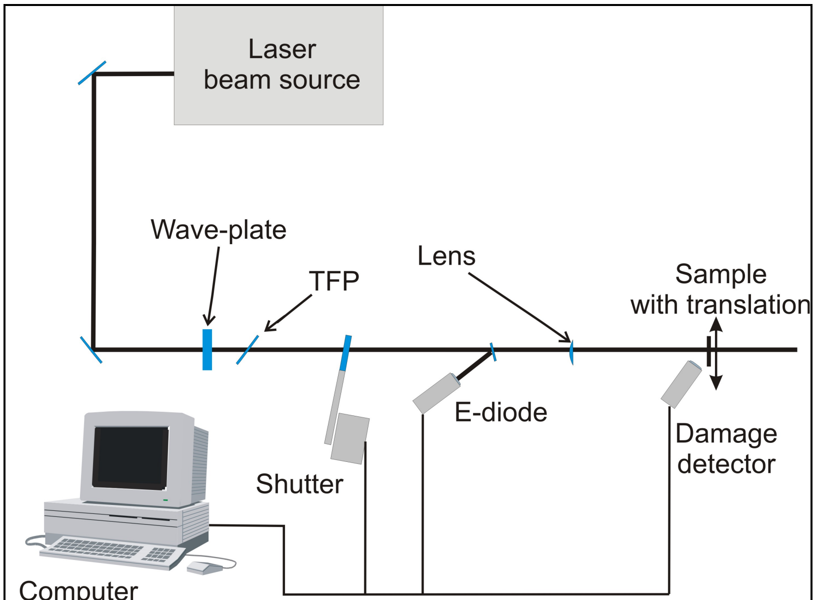

Fig. 4 Schematic drawing of the LIDT measurement set-up.

Considering the typical sources of error in the measurement facility, the absolute error can be estimated at 25%. To ensure constant measurement conditions for the entire test campaign, the pulse duration and the beam diameter were verified before each testing procedure. According to the observation of these laser parameters, the relative error of the LIDT-measurement can be assessed below 5%. Furthermore, a sample well characterised at the Round-robin experiment in 2004 [4,5] was measured periodically during the campaign for calibration.

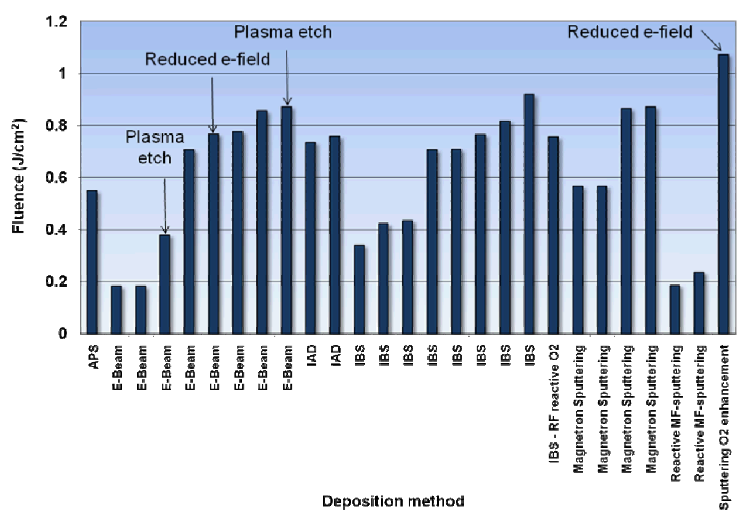

Fig. 5 Distribution of laser resistance as a function of deposition process.

5. Results

One of the most striking aspects of the damage threshold results is the 5:1 difference between the highest and lowest laser resistance for short pulses compared to last year's test long pulse (5 ns) high reflector coatings that had over 100:1 difference between the highest and lowest laser resistance. Clearly femtosecond laser damage is much more intrinsic in nature.[6,7] Another striking difference from last year's long pulse results is the number of deposition processes and the number of different materials that yield comparably high laser resistance as illustrated in figures 5 and 6.

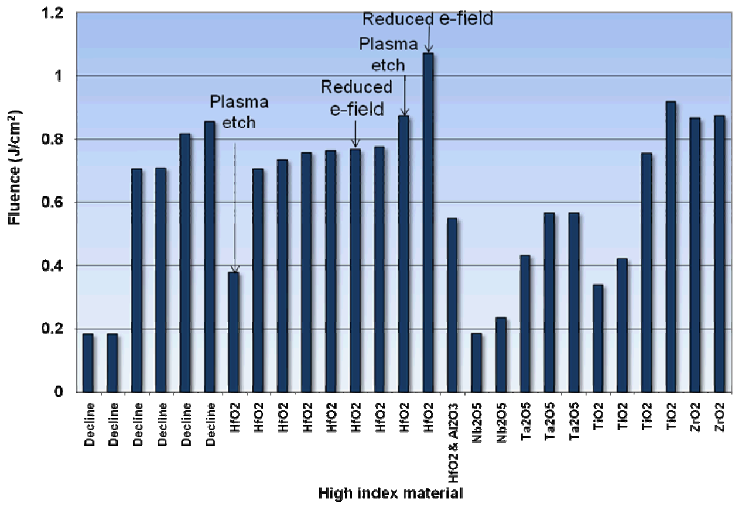

Fig. 6 Distribution of laser resistance as a function of high index coating material.

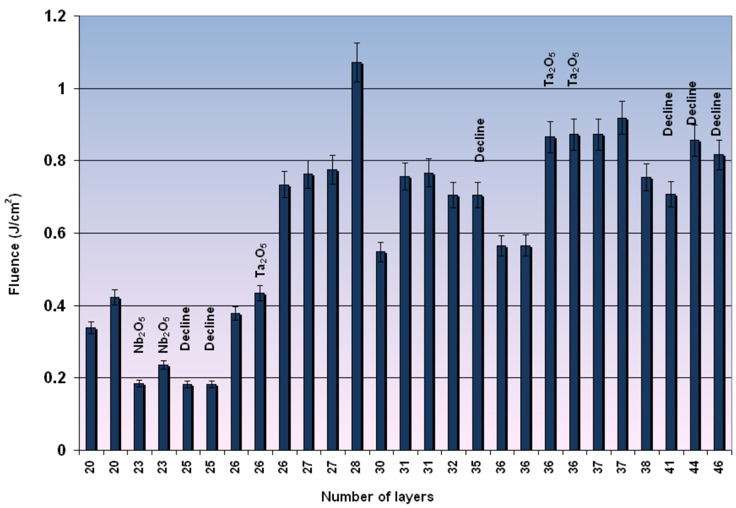

Fig. 7 Impact of layer count on laser resistance of submitted samples.

There was only a 20% difference between the laser resistance of the best hafnia, titania, and zirconia coatings. All of these materials are dioxides compared to the pentoxides, niobia and tantala, that did not perform nearly as well. Hafnia was clearly the most laser resistant high index material for the long pulse coatings.

Plasma pre-etching of the surface had a favorable impact on the laser resistance of one of the samples, but not nearly to the magnitude observed in the long pulse coatings from last year. Because of the expected more intrinsic damage mechanisms, reduced electric-field designs were also submitted yielding the highest laser resistant coating of the group. Electric-field reduction techniques consist of modifying the thicknesses of the outer layers (thinner high index and thicker low index layers) to reduce the electric field in the high index layers which tend to limit the laser resistance of the coating.[8] Typically the electric field is elevated in the silica layers, however, this material tends to be more laser resistant leading to a multilayer coating with an overall improved laser resistance.

In last year's damage competition, long pulse 1064 nm coatings tended to have greater laser resistance when they had silica overcoats as indicated by an even number of layers in the multilayer coating. Typically overcoats are half-wave optical thickness so are optically absentee, hence they don't reduce the reflectivity. With these assumptions, the data was analyzed by layer count to see if a pattern would emerge with respect to an odd versus even number of layers. No cross sections were made of the coatings to quantitatively determine the actual presence of overcoats and their respective physical thicknesses to protect the proprietary designs of each participant. Femtosecond pulse coatings do not appear to have a correlation between laser resistance for odd versus even layer count as illustrated in figure 7 so it is assumed that overcoats are neither helpful nor detrimental. What is observed is that lower layer counts tend to have lower laser resistance. One possible explanation for this behavior is that many of the lower laser resistant pentoxide materials have lower layer counts because of the greater refractive index difference between the high and low index materials as illustrated in figure 7. A further examination of the laser resistance as a function of reflectivity shown in figure 8 also illustrates a similar trend where the lower reflectivity mirrors tend to have lower thresholds. Unfortunately, the resolution of some of the reflectivity scans was low so many of the 99.5% reflectivity mirrors could in fact have had higher reflectivity. Again the low laser resistance trend appears to correlate more with the pentoxide high index material than with low layer count or low reflectivity.

6. CONCLUSIONS

The results of this damage study appear to suggest that femtosecond laser resistance of high reflectors tends to be much more intrinsic due to the lack of dependency on deposition process, high index coating material (except for pentoxides), and exterior coating material (overcoats), layer count and reflectivity. The high laser resistance of a reduced electric field design also suggests a more intrinsic damage mechanism. Further evidence of a deterministic mechanism is the smaller difference (5×) observed between the highest and lowest threshold coatings compared to the two orders of magnitude observed for last year's 5 ns pulse damage testing which appears to be a much more macro defect initiated damage process. High index materials that were dioxides tended to perform better than pentoxides. Lower reflectivity coatings tended to have lower laser resistance.

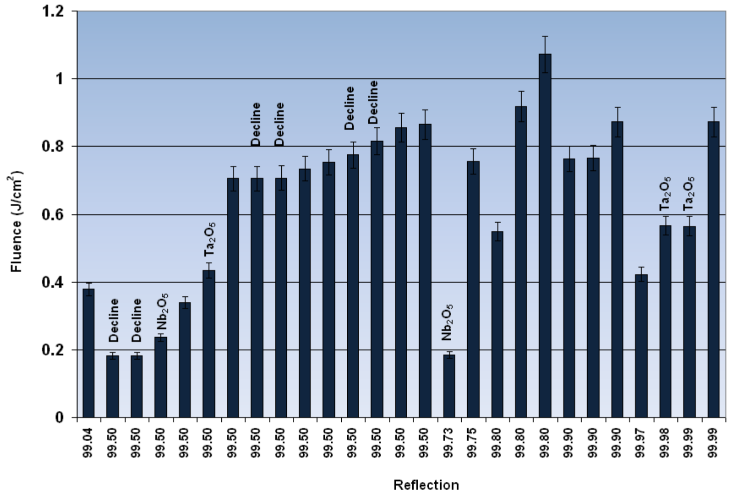

Fig. 8 Impact of reflectivity on laser resistance of submitted samples.

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